Nature Conservation

Nature Conservation 62: 261–287 (2026)
DOI: 10.3897/natureconservation.62.148938

Review Article

Building blocks for upscaling freshwater ecosystem restoration: Place-based strategies for a transdisciplinary challenge

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Abstract

Freshwater ecosystems are vital for biodiversity and human well-being, but remain amongst the most degraded globally. Nature-based Solutions (NbS) offer a promising pathway to restoration, yet implementation remains fragmented and often limited in scale. This paper synthesises insights from 18 demonstration cases across Europe, carried out under the EU Horizon 2020 MERLIN project, to identify key factors enabling the systemic upscaling of freshwater restoration through NbS. Drawing on practical experiences, five interdependent "building blocks" are proposed: (1) comprehensive status review; (2) narratives of the future; (3) evidence-informed approach; (4) resource management and (5) stakeholder engagement. These dimensions reflect cross-cutting challenges and capacities — such as context-sensitive planning, adaptive learning, financing strategies and inclusive governance. While grounded in diverse local contexts, the framework offers a strategic orientation for scientists, practitioners and policy-makers working to align restoration efforts with the ambitions of the European Green Deal and Nature Restoration Regulation. Rather than prescribing uniform solutions, the paper provides practice-informed guidance for embedding restoration in complex social–ecological systems.

OPEN ACCESS

Academic editor: Katrina Marsden
Received: 6 February 2025
Accepted: 30 November 2025
Published: 25 February 2026

ZooBank: https://zoobank.org/D0DA847D-CE7A-4B29-A8C6-DA0029A0799B

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Citation: Birk S, Anzaldua G, Baattrup-Pedersen A, Bérczi-Siket A, Blackstock K, Buijse T, Carmen E, Carvalho L, Garcia X, Gerner N, Grondard N, Hernandez Herrero E, Ibrahim A, Kok S, Lenz M-I, Nyírő F, Okruszko T, Penning E, Pott L, Rouillard J, Schmidt-Kloiber A, Schwerk A, Sommerhäuser MM, St. John R, Waylen K, Hering D (2026) Building blocks for upscaling freshwater ecosystem restoration: Place-based strategies for a transdisciplinary challenge. In: Kaden US, Schmid S, Wulf S, Marsden K, Klusmann C, Bonn A, Tockner K, Scholz M (Eds) Wetlands in a Changing Climate: Restoring Coasts and Floodplains. Nature Conservation 62: 261–287. https://doi.org/10.3897/natureconservation.62.148938

Highlights

- Synthesises lessons from 18 diverse freshwater restoration cases across Europe under the MERLIN project;
- Proposes five strategic building blocks for scaling Nature-based Solutions: system understanding, shared vision, evidence use, resource management and stakeholder engagement;
- Emphasises the interdependence of ecological, institutional and societal dimensions in upscaling restoration;
- Demonstrates the value of transdisciplinary collaboration, adaptive planning and embedded implementation;
- Offers practice-orientated insights aligned with the European Green Deal and Nature Restoration Regulation.

Key words: European Green Deal, MERLIN project, Nature-based Solutions, Nature Restoration Regulation, resource management, societal transformation, stakeholder engagement, systemic monitoring

Introduction

The accelerating climate and biodiversity crises demand urgent and coordinated responses, with ecosystem restoration increasingly recognised as a central strategy (UNEP 2021). Amongst the ecosystems most in need of attention are freshwaters, which provide multiple essential functions for human societies — such as clean water, flood regulation and food security — while also supporting extraordinary levels of biodiversity (Stammel et al. 2026). Yet they are disproportionately impacted by human activity and remain amongst the most degraded ecosystems globally (Reid et al. 2019; Tickner et al. 2020; Kaden et al. 2026). Their complex, interconnected hydrological networks at the catchment scale make them particularly vulnerable to pressures such as land-use change, pollution, flow regulation and climate-driven alterations (Birk et al. 2020; Fink et al. 2026).

Nature-based Solutions (NbS) have emerged as a promising approach to freshwater restoration, addressing these intertwined challenges by leveraging natural processes to deliver environmental, social and economic co-benefits (Cohen-Shacham et al. 2016; van Rees et al. 2023; Waylen et al. 2024). However, implementation often remains fragmented and limited in scale — posing a risk that the transformative potential of NbS will not be realised (Carmen et al. 2024). Scaling up NbS across regions and sectors is critical to achieving meaningful impact. Achieving systemic outcomes requires landscape-level strategies that reflect the complexity of freshwater systems within dynamic social–ecological systems (Ockendon et al. 2025).

Responding to this complexity requires a transformation in how scientific knowledge is produced and applied. Research on NbS increasingly aligns with the notion of post-normal science, which addresses complex societal problems where facts are uncertain, values are contested and stakes are high (Funtowicz and Ravetz 1993; Nowotny 2003). This implies a shift towards normative scholarship — a goal-orientated and transdisciplinary mode of science that seeks to generate actionable knowledge through mutual learning between researchers and societal actors (Ott and Kiteme 2016; Büttner et al. 2023). As such, res-

toration as NbS must be understood not only as an ecological task, but as a societal process requiring engagement, reflexivity and contextual sensitivity.

Scaling NbS for freshwater restoration likely requires strategies that are both systemic and attuned to local ecological, institutional and societal contexts. Such strategies do not arise from generic templates but are co-produced through local collaboration — supported by academic perspectives that span disciplinary boundaries, integrating ecological science with social, political and governance insights. While lessons from these settings are inevitably context-specific, they can nonetheless reveal broader patterns and shared challenges. This paper synthesises such bottom-up experiences, aiming to distil learning from diverse demonstration cases while acknowledging their limitations and variability.

MERLIN demonstration cases and place-based implementation

One initiative that sought to support grounded, systemic scaling is the Horizon 2020 innovation project MERLIN (www.project-merlin.eu). It brought together 18 demonstration cases of freshwater restoration across Europe — ranging from rivers and floodplains to peatlands and other wetlands — each situated in distinct ecological and governance settings. MERLIN involved 47 partner institutions working to advance the mainstreaming of freshwater restoration through NbS. These efforts were guided by the overarching ambition of the European Green Deal, which positions ecosystem restoration as a critical lever for enabling just and sustainable transitions (EC 2022).

The project addresses long-standing barriers to effective restoration — such as stakeholder resistance, limited policy traction and insufficient funding — by demonstrating how NbS can deliver ecological, social and economic benefits in tandem. By reframing restoration as a contributor to broader societal goals — public health, water security, disaster risk reduction and sustainable development — MERLIN expands its appeal to a wider set of stakeholders. In this framing, biodiversity is not the sole end-point, but a co-benefit that helps unlock political and financial support (Carmen et al. 2024).

The 18 demonstration cases span diverse freshwater systems and are grouped into three main types: small streams and their catchments, peatlands and other wetlands, and large transboundary rivers. Geographically, they stretch from northern Finland to southern Portugal and from the British Isles to the Northern District of Israel (Fig. 1). Each case represents a locally grounded effort to apply NbS in ways that respond to regional priorities, institutional capacities and restoration ambitions.

MERLIN demonstration cases engage with societal challenges including water quality, climate adaptation, flood and drought risk, biodiversity loss and community resilience. Restoration actions vary widely — from technical measures like barrier removal, floodplain reconnection and rewetting, to soft measures, such as stakeholder incentives, outreach campaigns and environmental education (Fig. 2; see also Pott et al. (2025)). All cases adopted a transdisciplinary "living lab" approach, bringing together practitioners, researchers and local stakeholders in co-creative processes (Seidl et al. 2013; Fischer et al. 2021).

Crucially, these interventions did not take place in isolation. MERLIN deliberately embedded its actions within existing long-term restoration processes at each site, aligning with local strategies, governance systems and visions for socio-ecological change. By contributing tangible measures

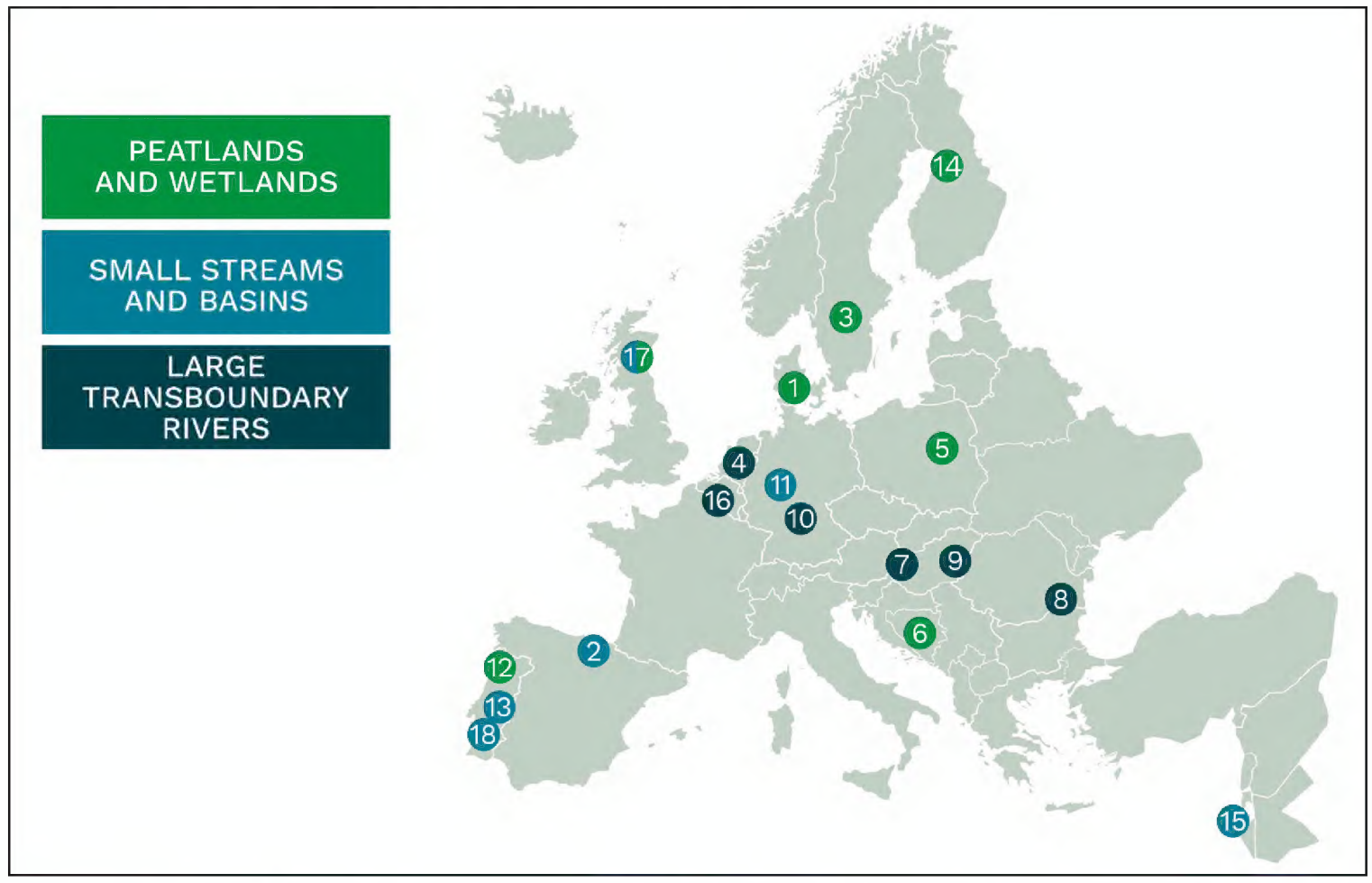

Figure 1. Location of the 18 MERLIN demonstration cases, categorised by ecosystem type. (1) Kvorning wetland rewetting, Denmark; (2) Deba barrier removal, Spain; (3) Beaver River engineering, Sweden; (4) Room for the Rhine, the Netherlands; (5) Kampinos wetland rewetting, Poland; (6) Hutovo Blato peatland rewetting, Bosnia; (7) Danube floodplain restoration, Austria and Danube sidearm reconnect, Hungary; (8) Danube floodplain reconnect, Romania; (9) Tisza floodplain rewetting, Hungary; (10) Blue Belt Germany, Germany; (11) Emscher Basin restoration, Germany; (12) Lima River forest restoration, Portugal; (13) Sorraia River restoration, Portugal; (14) Komppasuo peatland rewetting, Finland; (15) Tzipori Basin restoration, Israel; (16) Upper Scheldt restoration, Belgium; (17) Forth Basin restoration, United Kingdom; (18) Ervidel River restoration, Portugal. Figure taken from Pott et al. (2025).

during the 4.5-year project period, the demonstration cases reinforced and accelerated pre-existing initiatives — delivering visible results while enhancing continuity beyond the project's duration. This embeddedness not only enabled implementation, but also amplified ongoing transformation trajectories, thereby increasing the likelihood of lasting impact.

Synthesis approach and analytical basis

To synthesise the diversity of experiences across the MERLIN demonstration cases and to identify transferable insights, this paper adopts a narrative structure, based on five interdependent dimensions that emerged within the project as central to effective upscaling. These dimensions — referred to here as "building blocks" — are: (1) comprehensive status review; (2) narratives of the future; (3) evidence-informed approach; (4) resource management, and (5) stakeholder engagement. Rather than reporting the results of a singular empirical study, the paper organises MERLIN's outcomes around these building blocks to provide a translatable orientation for the various actors involved in freshwater restoration.

The building block structure was developed during MERLIN's synthesis phase through iterative review of case documentation, thematic deliverables, participatory scenario-building, reflective planning tools and project-wide reflection. The aim was to reveal recurring challenges, needs and enablers from across diverse contexts and to host these within a framework that makes them accessible to applied scientists, decision-makers and practitioners.

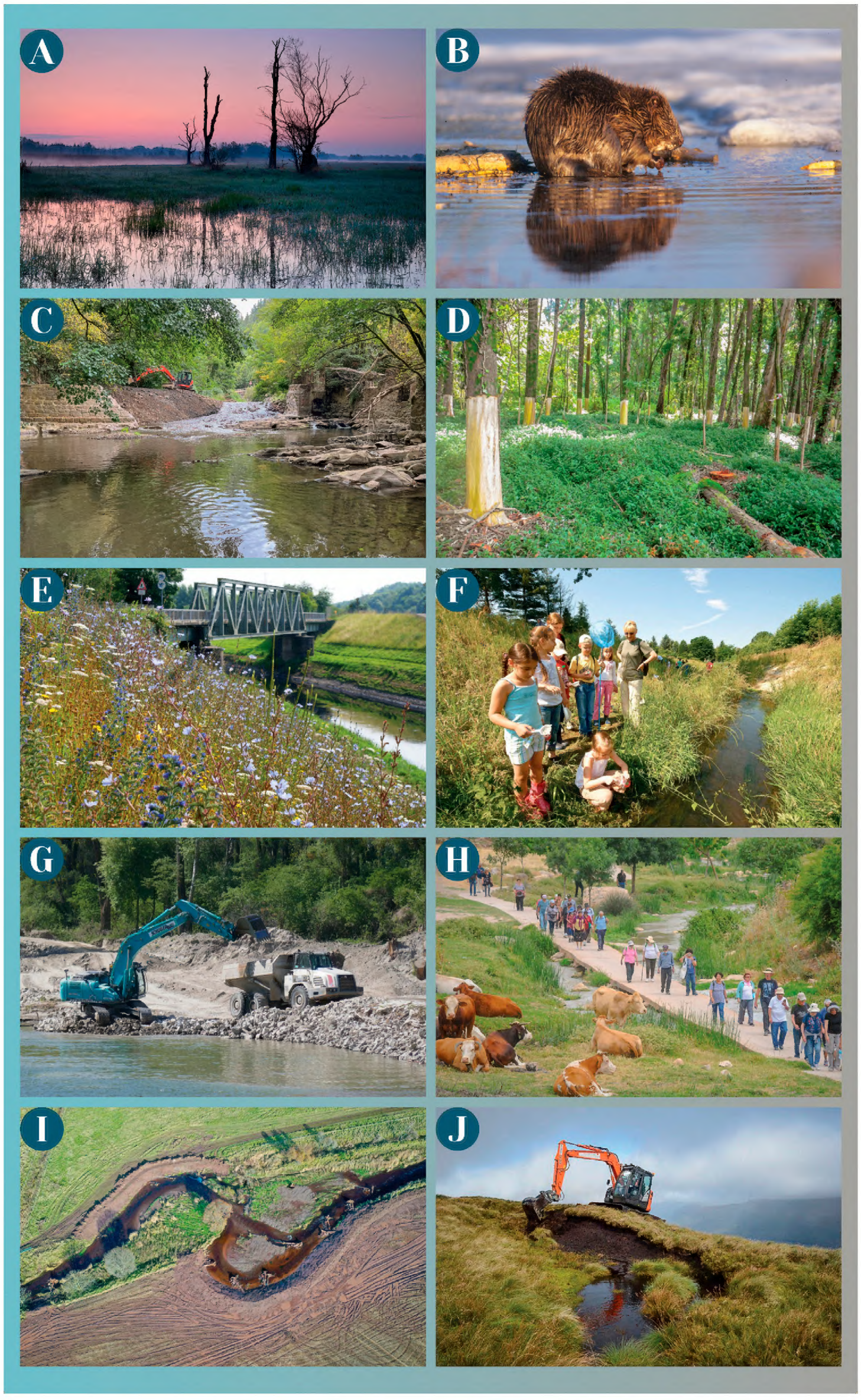

Figure 2. Selected examples of various freshwater restoration measures implemented in MERLIN demonstration cases: **A.** Wetland rewetting in Kampinos National Park, Poland; **B.** River engineering by beavers, Sweden; **C.** Barrier removal in the Deba River system, Basque Country, Spain; **D.** Invasive species control through *Eucalyptus* debarking, Lima catchment, Portugal; **E.** Planting flower meadows on embankments along the Emscher River, Germany; **F.** Youth education programme on river restoration in the Emscher Basin, Germany; **G.** Removing armour stones in Donau-Auen National Park, Austria; **H.** Community events for Tzipori River restoration, Israel; **I.** Meander restoration in streams within the Forth Basin, Scotland; **J.** Ditch-blocking for peatland rewetting in the Forth Basin, Scotland.

The resulting synthesis does not claim empirical generalisability, but instead seeks to offer strategic and practice-relevant insights. These are intended to provide information for freshwater restoration efforts aligned with the broader ambitions of the European Green Deal, including the EU Biodiversity Strategy 2030 and the Nature Restoration Regulation (EC 2020; EC 2022; Hering et al. 2023). This paper elaborates each building block in turn, followed by a discussion that synthesises their interplay across cases, reflects on contextual limitations and distils broader insights for effective, scalable and policy-relevant freshwater restoration.

Strategic building blocks for scaling freshwater restoration

Each building block corresponds to a critical area of practice and learning:

1. Comprehensive Status Review – Understanding the System: Effective restoration begins with a sound understanding of the social–ecological system. This building block emphasises the need for comprehensive system diagnostics, integrating ecological and societal dimensions, to identify key challenges, governance constraints and strategic entry points for intervention.
2. Narratives of the Future – Developing a Shared Vision: Restoration requires more than technical solutions; it depends on compelling visions that align actors and guide coordinated action. This building block focuses on the co-creation of forward-looking narratives that combine scientific insight with stakeholder perspectives, helping to frame objectives, justify interventions and navigate uncertainties.
3. Evidence-Informed Approach – Integrating Knowledge into Adaptive Action: Planning and implementation of NbS must be grounded in empirical knowledge while remaining adaptive to emerging insights. This building block highlights the role of systemic monitoring, impact evaluation and critical synthesis in supporting learning-orientated governance and enhancing the credibility of restoration outcomes.
4. Resource Management – Mobilising and Aligning Enabling Conditions: Scaling up restoration requires stable and diversified resourcing. This building block addresses the financial and institutional capacities needed to implement and sustain restoration efforts, including public funding instruments, blended finance strategies and the development of financial literacy amongst restoration actors.
5. Stakeholder Engagement – Building Legitimacy, Ownership and Capacity: Lasting restoration depends on inclusive engagement across society and sectors. This building block highlights the need for fair representation, shared decision-making and equitable benefit-sharing — positioning stakeholder engagement, spanning civil society, public institutions and economic sectors, as a structural condition for just and durable transformation.

The building blocks are not strictly sequential. Rather, they represent interdependent functions that must be addressed in parallel and revisited iteratively throughout the restoration process. While Fig. 3 conveys a typical progression — where pressing socio-ecological challenges serve as the catalyst for planning, implementation and eventual consolidation — this trajectory is governed

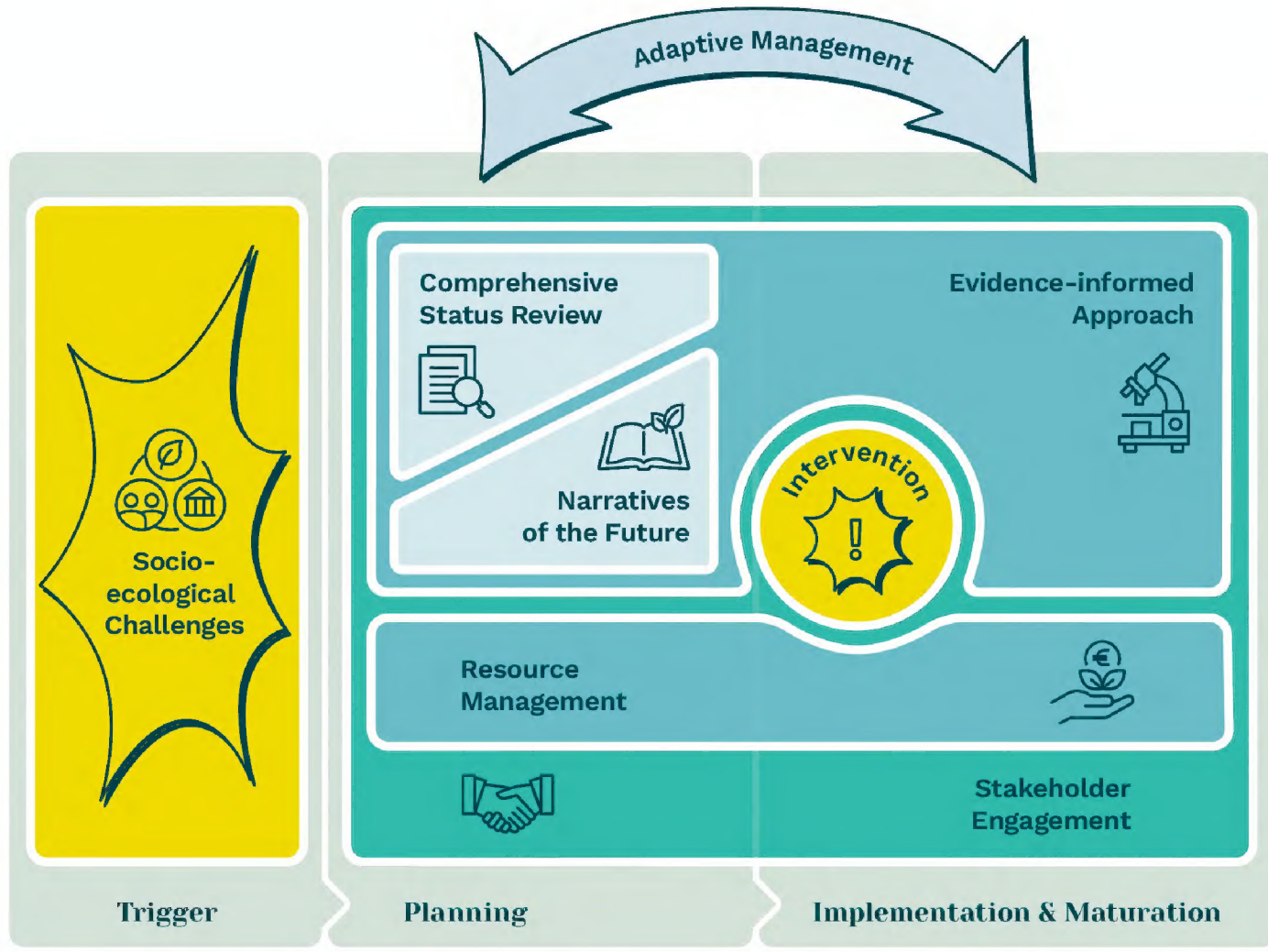

Figure 3. Strategic Building Blocks for Scaling Freshwater Restoration. The figure presents five interdependent building blocks for designing, implementing and scaling Nature-based Solutions in freshwater restoration: (1) Comprehensive Status Review; (2) Narratives of the Future; (3) Evidence-Informed Approach; (4) Resource Management and (5) Stakeholder Engagement. These blocks fulfil essential functions — from understanding the system and co-creating visions, to grounding actions in evidence, securing resources and fostering legitimacy. While not strictly sequential, they typically progress from identifying socio-ecological challenges to planning, implementation and maturation. All steps follow an adaptive management logic of continuous learning and revision. Stakeholder engagement underlies the entire process, enabling collaboration, accountability and sustained transformation.

by an adaptive management logic that emphasises iterative learning and adjustment. Stakeholder engagement, in this context, is not an isolated step, but a cross-cutting prerequisite for legitimacy, coordination and long-term effectiveness across all stages.

Building block 1: comprehensive status review

Freshwater restoration depends on a clear understanding of ecological and societal systems. This building block emphasises the need to systematically assess both ecological conditions and societal dynamics to establish a solid foundation for planning and implementation. Restoration is often triggered by pressing environmental and societal challenges — such as biodiversity loss, degraded ecosystem services or climate-related impacts like floods and droughts (e.g. Nehren et al. (2023)). Despite legal obligations under instruments, such as the EU Water Framework Directive and the Nature Restoration Regulation, restoration is frequently hampered by diverging land-use interests, institutional fragmentation and political hesitation (Cortina-Segarra et al. 2021). Thus, understanding the social landscape — including conflicting interests and governance constraints — is just as vital as diagnosing ecological conditions. Responding effectively requires not only data, but an appreciation of system interdependencies, actor relationships and entry points for constructive alignment and shared initiative.

Socio-institutional scoping: understanding the people in the system

Restoration takes place in contested social spaces (Wantzen and Cao 2026). A comprehensive status review must therefore incorporate a structured analysis of stakeholders and institutions: who influences decisions, who is impacted and who is currently excluded. In MERLIN, most demonstration cases were embedded in long-standing restoration contexts with pre-existing stakeholder networks. Structured mapping was rarely conducted before, but proved valuable as a reflective tool to revisit and re-assess these actor landscapes. Teams characterised stakeholders using attributes, such as interest, influence, knowledge, leadership and alliances. This helped anticipate support or resistance, recognise under-represented voices and prepare more inclusive engagement strategies (Ibrahim et al. 2025).

System reflection: taking stock of needs, barriers and potential

Complementing stakeholder mapping, MERLIN teams conducted systematic analyses of Strengths, Weaknesses, Opportunities and Threats (SWOT) to identify enabling and limiting conditions for restoration (Buijse et al. 2022). These analyses followed a harmonised format, based on the IUCN Global Standard for Nature-based Solutions (Le Gouvello et al. 2023) and were applied across all demonstration cases. The aim was to reflect on how existing restoration efforts aligned with the broader goals of the European Green Deal and to explore ways to optimise them.

The SWOT reflections revealed opportunities for broader societal buy-in by linking restoration to multiple goals such as health, flood protection, job creation and education. They also uncovered technical, regulatory and economic gaps — particularly around the integration of socio-economic expertise. In many cases, teams identified potential to broaden coalitions and strengthen implementation by reframing restoration not merely as a conservation task, but as a vehicle for societal benefit.

These insights were echoed in MERLIN's Theory of Change (ToC) workshops, where key challenges and assumptions were identified across demonstration cases (Pott et al. 2025). While further elaborated in Building Block 2, these initial steps to establish the ToC helped clarify the system's preconditions. Together, stakeholder mapping, SWOT analysis and ToC provided a multifaceted lens to understand where and how restoration can be most effective and legitimate.

Pan-european perspectives on restoration needs and opportunities

While the focus of this first building block lies on case-level diagnostics, MERLIN also developed a European-scale screening of freshwater restoration needs and potential. This mapping synthesised diverse environmental datasets across Europe at the resolution of River Restoration Units (Duarte et al. 2025), combining ecological status, species distributions, ecosystem service delivery, human pressures and enabling factors, such as Natura 2000 protection status. The maps visualise spatial patterns of restoration priorities across Europe and serve as a strategic reference for EU-level planning and awareness-raising (Duarte et al. 2023). They complement local

assessments by providing a broader context and help align catchment-scale planning with transnational restoration ambitions, such as those outlined in the EU Biodiversity Strategy and Nature Restoration Regulation.

Building block 2: narratives of the future

Restoration initiatives benefit from clear, forward-looking narratives that align local priorities with broader policy ambitions. High-level goals such as the Global Biodiversity Framework's vision of "living in harmony with nature" (Convention on Biological Diversity 2022) or the EU Biodiversity Strategy's "path to recovery by 2030" (EC 2020) require contextualisation to become actionable (Szetey et al. 2021). Yet, translating such ambitions into place-based implementation often proves difficult (Ansell et al. 2022). This building block focuses on developing locally meaningful narratives of the future that help frame objectives, guide decisions under uncertainty and engage stakeholders around shared visions.

Qualitative co-visioning: theory of change as a planning and communication tool

Narratives become most meaningful when co-created amongst the actors shaping restoration on the ground. In MERLIN, demonstration case representatives collaboratively developed Theory of Change pathways to structure their ambitions and guide strategic decisions (Pott et al. 2025). These pathways outlined how specific restoration measures were expected to contribute to longer-term outcomes for biodiversity, climate resilience and societal well-being (Fig. 4). The co-creation process fostered reflection on underlying assumptions, trade-offs and knowledge gaps, while aligning local objectives with the broader goals of the European Green Deal. In doing so, NbS were positioned not merely as technical interventions, but as integral components of socially relevant futures.

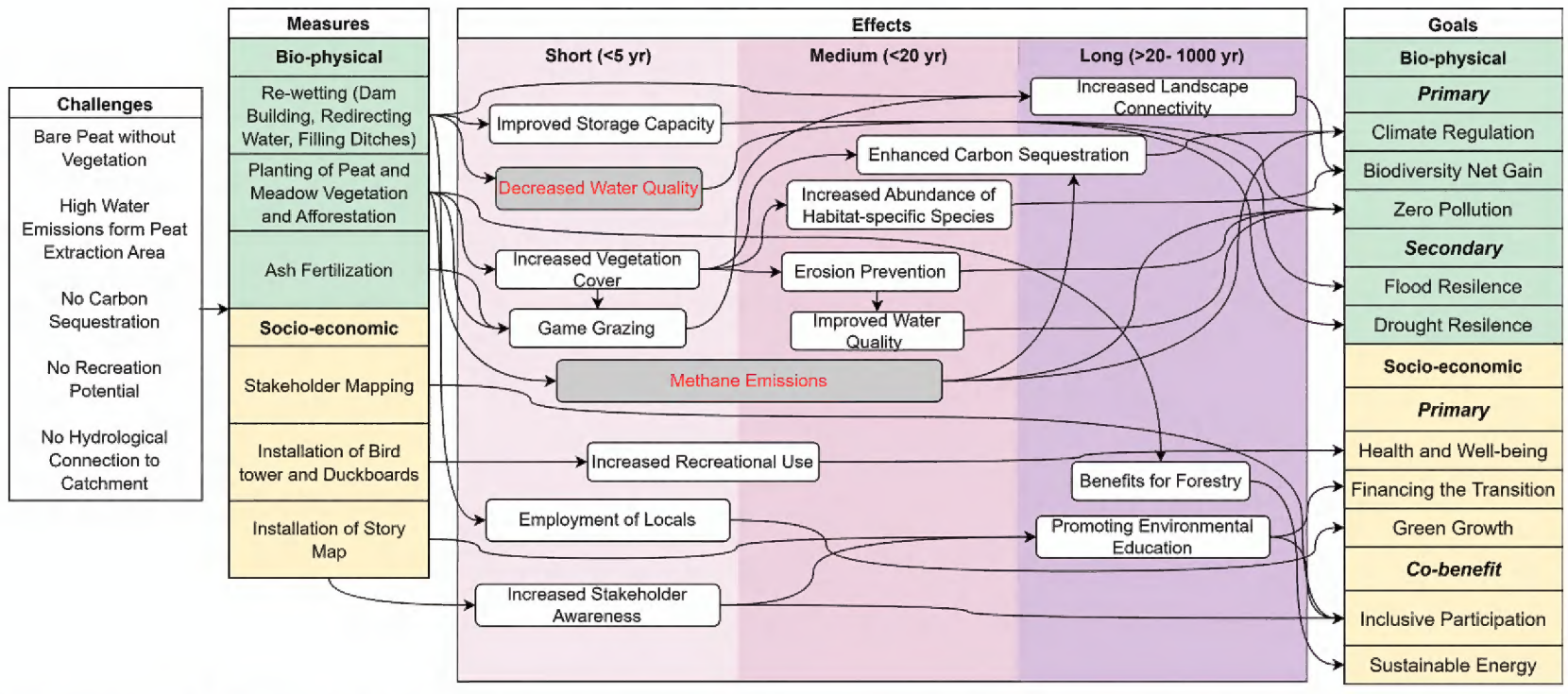

Figure 4. Theory of Change for the restoration demonstration case of the Komppasuo peat extraction area in Finland. The figure illustrates how specific local challenges — such as bare peat, hydrological disconnection and high greenhouse gas emissions — are addressed through biophysical and socio-economic restoration measures. From left to right, the diagram traces the expected short-, medium- and long-term effects, culminating in overarching restoration goals aligned with European policy goals. Arrows indicate assumed cause-effect relationships. Potential negative outcomes are marked in red font and their boxes are shaded in grey. Figure taken from Pott et al. (2025).

Quantitative modelling and scenario-based planning

Data-driven projections complement qualitative visions by providing tangible estimates of future outcomes. MERLIN applied several modelling tools to support this:

- Pan-European perspective: A scenario mapping framework (Funk et al. in review) aligned policy indicators across the Water Framework Directive and Habitats Directive to prioritise areas for restoration. Supporting this analysis, a Delphi expert survey identified restoration measures most likely to enhance ecosystem services (Birk et al. 2025).
- Regional ecosystem service modelling: Kok et al. (2025) used an integrated ecosystem service framework to assess trade-offs across different ecosystem services under three restoration strategies in the Rhine floodplains. This facilitated a comprehensive cost-benefit analysis, providing insights into socio-economic impacts (Table 1).
- Landscape-scale modelling workflow: Garcia et al. (2025) provided step-by-step guidance to simulate biophysical and economic effects of freshwater restoration. Built around the open-source SWAT+ modelling framework and using harmonised pan-European datasets, the workflow enables case teams to project restoration outcomes.

These tools allowed demonstration cases to compare intervention scenarios, visualise synergies and trade-offs and communicate benefits more convincingly to stakeholders and funders.

Regional scalability plans: co-developed strategies for landscape-level impact

The narratives culminated in MERLIN's Regional Scalability Plans (Ojanen et al. 2024), co-developed with stakeholders to support upscaling over the 2025–2050 timeframe. Each plan addressed the 'Why', 'Where', 'What', 'How' and 'Who' of restoration, rooted in NbS thinking and orientated towards multiple European Green Deal goals. While these plans varied in scope and maturity, all aimed to extend restoration beyond demonstration cases to broader catchment and policy levels. They proposed concrete actions, financing models and governance pathways tailored to regional contexts. Despite political and economic uncertainties, the co-creation of these plans illustrated that ambitious restoration pathways can be developed collaboratively when anchored in shared narratives of the future.

Building block 3: evidence-informed approach

Effective upscaling of NbS depends on robust, actionable evidence (Cvijanović et al. 2026; Penning et al. 2023). Demonstrating what works, for whom and under what conditions is essential not only for justifying investment, but also for enabling strategic planning and adaptive implementation. Without evidence of impact, NbS risk being perceived as symbolic rather than transformative (Chausson et al. 2020). This building block highlights the importance of grounding restoration efforts in systemic monitoring, evaluation and learning.

Table 1. Overview of three restoration strategy scenarios for the Rhine floodplains as assessed in Kok et al. (2025), comparing intervention characteristics and socio-economic outcomes. The analysis applied a comprehensive ecosystem service framework to evaluate trade-offs and synergies across multiple ecosystem services. Narrow and broad benefit–cost ratios were calculated, based on different valuation scopes. Scenario S1 focuses on improving flood and drought protection, while S2 and S3 ("Room for Living Rivers") increasingly prioritise ecological restoration and land-use conversion, with S3 representing the most ambitious strategy.

Alternatives			S1: Room for the River –floods and droughts	S2: Room for Living Rivers	S3: Room for Living Rivers+
Intervention	Discharge capacity	Dyke relocation	22 km; +2700 ha	74 km; +4100 ha	74 km; +4100 ha
		Side channels	36 km	118 km	118 km
		Floodplain lowering	65 km	-	-
	Erosion management		Maintain current riverbed level	Restore bed level of year 2000	Restore bed level of year 2000
	Floodplain land use		59% Agri (+7%)	29% Agri (-23%)	0% Agri (-52%)
Results	Costs (Billion €)		-4.4	-5.3	-5.9
	Benefits (Billion €) *broad*[2]		1.1	4.6	7.6
	Benefit-Cost Ratio narrow[1]		**0.10**	**0.03**	**0.03**
	Benefit-Cost Ratio broad[2]		**0.25**	**0.87**	**1.27**

[1] including only direct benefits: Agricultural yields, flood protection, navigation.
[2] including all benefits *above* plus carbon sequestration, nutrient retention, recreation, amenity, bequest and existence.

From ecological data to systemic impact

In NbS contexts, evidence must go beyond measuring ecological change. Restoration interventions are expected to deliver co-benefits for biodiversity, climate resilience and social well-being. Recognising this, MERLIN developed a shared monitoring framework aligned with the European Green Deal goals (Carvalho et al. 2022). The framework incorporates 13 criteria ranging from biodiversity net gain and climate regulation to job creation, inclusive governance and circular economy (Fig. 5). For each, demonstration cases were encouraged to identify relevant indicators, establish baselines and collect data using comparable methods. A subset of these were identified as "Essential Restoration Variables" applicable across most cases. These included species richness, water storage capacity, greenhouse gas emissions and socio-economic indicators, such as stakeholder representation and financial leverage.

Outcomes and lessons from MERLIN monitoring

MERLIN demonstration cases applied this monitoring framework with varying levels of success and resource availability. The strongest quantitative evidence emerged for environmental goals — notably biodiversity and climate regulation. Across the 18 cases, Schwerk et al. (2025) reported the reconnection of 287 km of rivers and rewetting of 1,528 ha of floodplain or peatland habitats.

Positive results were also noted for social and economic indicators, including increased recreational access, local job creation and stakeholder engagement. However, monitoring data were more limited for sectoral criteria, such as sustainable energy and transport, often due to resource constraints or perceived irrelevance at the local scale.

Trade-offs were documented as well. In some wetland cases, rewetting initially increased pollutant mobilisation, while agricultural land conversion

Figure 5. Systemic monitoring framework developed within MERLIN to assess the impacts of freshwater restoration measures in alignment with the European Green Deal. The framework covers 13 interrelated criteria across environmental, social and economic domains — including biodiversity net gain, climate regulation, flood and drought resilience, circular economy, financing the transition and inclusive governance. It enabled consistent, multidimensional evaluation of restoration outcomes across MERLIN's demonstration cases.

conflicted with food production goals. These findings underline the importance of using evidence not just to demonstrate success, but to provide information for transparent decision-making and adaptive management.

Using evidence in complex systems

Restoration outcomes often emerge over long timescales and reflect complex interactions amongst ecological, social and institutional dynamics. As causality is rarely linear or demonstrable within typical project durations, MERLIN promoted an evidence-informed approach — acknowledging that data-driven insights must be complemented by expert judgement, qualitative understanding including the context and narrative accounts. This framing avoids the rigidity sometimes associated with "evidence-based" models and better reflects the adaptive, context-sensitive nature of NbS implementation (Adams and Sandbrook 2013). Systemic monitoring, thus, becomes not just a scientific task, but a practice of strategic learning: The same intervention may yield different results depending on biophysical settings, governance structures and stakeholder dynamics.

Strategic value for policy and scaling

MERLIN's impact monitoring contributes to a growing body of practice demonstrating how evidence-informed approaches to NbS can deliver co-benefits aligned with high-level policy goals (e.g. Corgo et al. (2024); Klusmann et al. 2026). The integrated design and implementation of MERLIN's framework provide a replicable example of how to align local monitoring with strategic restoration objectives, such as those outlined in the Nature Restoration Regulation. However, realising this potential requires sustained investment in monitoring infrastructure, long-term data continuity and policy uptake. Evidence-informed approaches should not be an afterthought, but a core component of restoration strategy (Spray et al. 2022).

Building block 4: resource management

Meeting the ambitions of freshwater ecosystem restoration across Europe demands reliable and diversified funding. While current projects often rely on short-term public grants, upscaling restoration to landscape level requires sustained financial strategies (Ockendon et al. 2025). The funding gap is substantial: estimated at €8–25 billion annually to meet EU policy targets, including the Biodiversity Strategy and Nature Restoration Regulation (WWF EPO 2024). Bridging this gap requires not only more resources, but also new capacities within restoration teams to access and manage diverse funding streams.

Navigating public and private funding sources

Public funding remains the cornerstone of restoration finance, particularly for projects that deliver public goods like biodiversity protection, water quality and recreation (UNEP 2023). EU instruments such as LIFE, CAP eco-schemes and national green infrastructure programmes are key enablers. However, these funds are often tied to short project cycles (typically 3–5 years) and burdened by administrative complexity (Rouillard et al. 2026). Effective upscaling needs longer-term, stable funding aligned with strategic implementation pathways (Nesbit et al. 2022). MERLIN insights confirm that, while restoration teams are familiar with public funding processes, these mechanisms rarely provide the flexibility or continuity required for lasting impact.

Diversifying funding sources inevitably involves greater private sector engagement. Yet MERLIN observed widespread caution and limited experience amongst restoration teams when it comes to accessing private finance. Barriers include unfamiliarity with financial terminology, uncertainty about how private sector involvement aligns with ecological goals and the challenge of articulating viable business models (Rouillard et al. 2025). Still, private engagement is feasible when aligned with motivations, such as corporate social responsibility, risk reduction or long-term investment in beneficial ecosystem services. While not always profit-driven, private actors require transparency, evidence and trust — conditions that restoration teams can foster by demonstrating clear benefits and shared goals.

Building financial literacy and strategy

Rouillard et al. (2025) developed a practical framework to support restoration teams in designing robust financial strategies. This four-pillar approach includes: (A) project planning and stakeholder engagement to explore private-sector motivations; (B) cost-benefit assessment to identify high-value options; (C) diversification of funding and revenue streams; and (D) alignment of financing strategies with long-term restoration goals (Fig. 6). Building this capacity means embracing a broader perspective — communicating across disciplines and engaging early with potential partners. Restoration teams that invested in financial literacy, hired support or built collaborations reported better prospects for durable implementation and scaling.

Creating enabling conditions: what needs to change beyond the project level

Overall, a wider institutional support is still essential to make financial diversification work. Stable and coherent regulation, especially enforcement of the polluter-pays principle, reduces risk and increases investor confidence. Governance structures must encourage cross-sector collaboration, while managing conflicts and incentives transparently. Without adequate regulatory backstops,

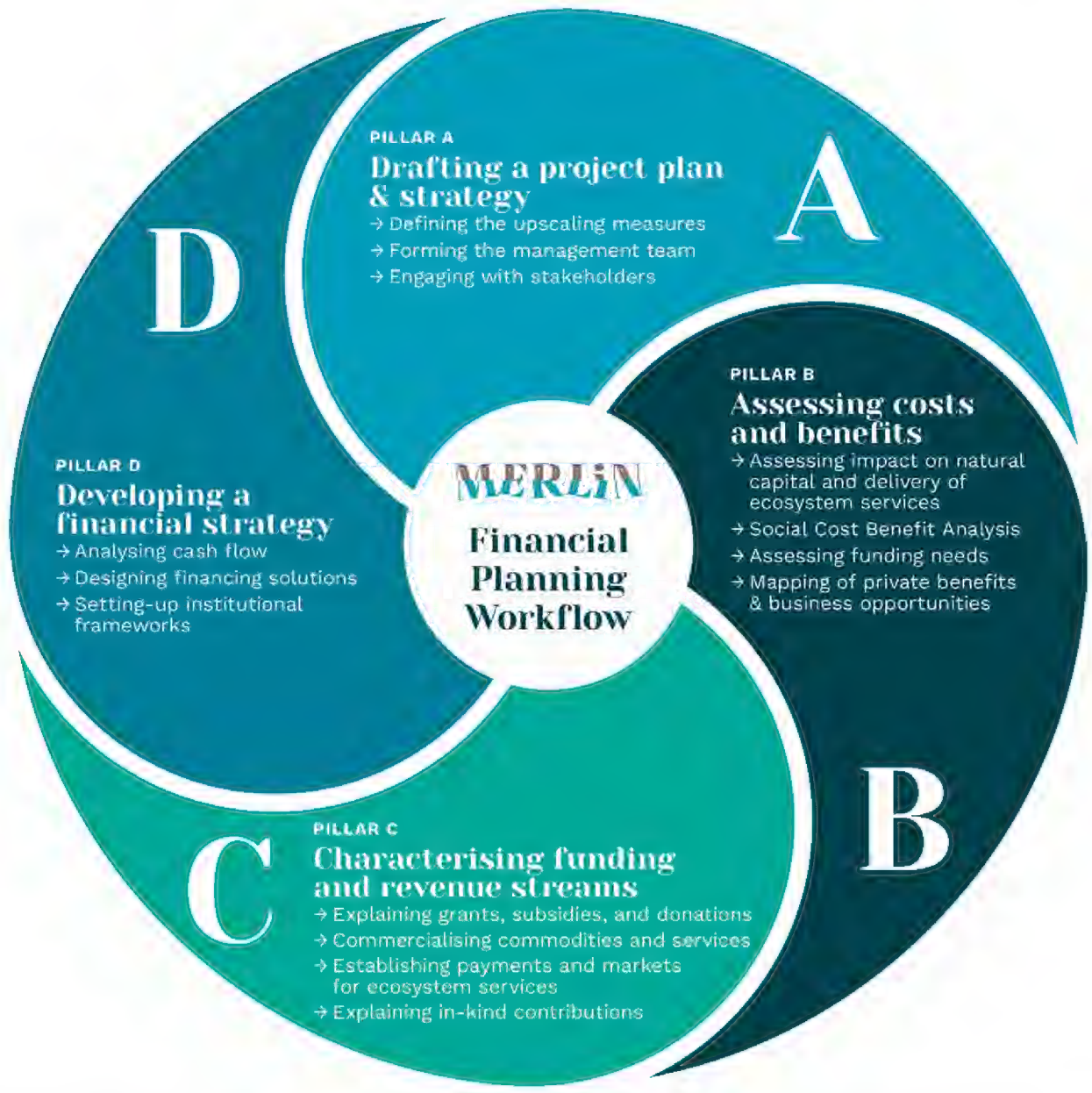
PILLAR A
Drafting a project plan & strategy
→ Defining the upscaling measures
→ Forming the management team
→ Engaging with stakeholders
A
PILLAR B
Assessing costs and benefits
→ Assessing impact on natural capital and delivery of ecosystem services
→ Social Cost Benefit Analysis
→ Assessing funding needs
→ Mapping of private benefits & business opportunities
B
PILLAR C
Characterising funding and revenue streams
→ Explaining grants, subsidies, and donations
→ Commercialising commodities and services
→ Establishing payments and markets for ecosystem services
→ Explaining in-kind contributions
C
PILLAR D
Developing a financial strategy
→ Analysing cash flow
→ Designing financing solutions
→ Setting-up institutional frameworks
D
MERLIN
Financial Planning Workflow

Figure 6. MERLIN Financial Planning Workflow. This four-pillar framework guides restoration teams in building viable financial strategies for upscaling. Pillar A lays the managerial foundation — defining measures, forming a competent team and engaging stakeholders. Pillar B assesses societal value and investment potential through biophysical and socio-economic analysis. Pillar C explores diverse funding and revenue streams. Pillar D focuses on planning cash flows and setting up institutional structures for implementation. Together, the pillars support strategic, cross-sectoral financial planning for freshwater restoration (Rouillard et al. 2025).

efforts to engage private capital risk being ineffective or misaligned with ecological goals. Equally important are support programmes, pilot initiatives and legal guidance to help teams navigate technical and relational barriers on the path to sustainable restoration finance (EIB 2023; UNEP 2023).

In addition to financial structures, the long-term viability of restoration efforts hinges on enabling institutional arrangements. Government commitment, cross-sectoral alignment and administrative mandates are essential for ensuring continuity beyond project cycles. Where public authorities actively supported restoration – through planning mandates, policy integration or dedicated staffing — MERLIN cases reported greater leverage in securing resources and scaling action (Ojanen et al. 2024).

Building block 5: stakeholder engagement

Restoration efforts succeed not only through robust planning, funding or technical expertise, but by embedding those efforts within the social systems they affect. Stakeholder engagement is thus not an add-on — it is a structural element for upscaling freshwater restoration through NbS. MERLIN's 18 demonstration cases illustrate that restoration must navigate complex landscapes of values, interests and power. Engaging communities, institutions and economic actors ensures not just smoother implementation, but shared legitimacy, broader ownership and greater resilience of outcomes over time.

Advancing just transformations through local engagement

Ibrahim et al. (2025) analysed engagement across all MERLIN demonstration cases through the lens of justice — representation, procedure and distribution. The analysis revealed that public actors dominated many processes, with comparatively limited involvement of community groups, smallholders or marginalised actors. Still, many cases progressed from simple information sharing to more collaborative formats, often via stakeholder boards or participatory workshops. These structures allowed for knowledge exchange and decision-making, though power asymmetries remained.

While perceived benefits, such as improved flood protection or biodiversity gains, were broadly acknowledged, the uneven distribution of burdens and unclear compensation mechanisms were frequently cited. Some cases showed how long-standing relationships could foster trust and continuity; others revealed how poor procedural inclusion could spark resistance. The key lesson: equitable and sustained engagement fosters not only fairer outcomes, but also stronger, context-sensitive alliances capable of carrying restoration beyond the project lifecycle.

Economic sectors as partners in landscape restoration

NbS uptake at landscape scale depends on integrating the economic sectors that both shape and depend on freshwater ecosystems. In MERLIN, Sectoral Strategies were developed with six sectors: agriculture, hydropower, insurance, navigation, peat extraction, and water supply. Communities of Practice were formed with stakeholders from each sector to explore shared goals and define pathways for NbS adoption (Bérczi-Siket et al. 2023).

Hydropower Sector Strategy
Involving the Hydropower Sector in strategic barrier removal: applying an NbS approach
Read the strategy here
Provide Sector specific tools to design NbS programmes with barrier removal
E Action
A Action
Increase understanding of an NbS approach to barrier removal
NbS in this context
Strategic removal of transversal barriers with no economic value to benefit the Hydropower Sector.
B Action
Highlight synergies between energy/ climate change and nature restoration policies
Build Sector capacity for leadership and collaboration
D Action
Develop finance pathways guided by an NbS approach
C Action
2030 Vision
→ Barrier removal and NbS approach embedded in company strategies
→ Works in partnership to remove barriers
→ Has the relevant skills and expertise for ambitious action
NbS – Nature-based Solutions
MERLIN
www.project-merlin.eu
freshwaterblog.net
merlin-project
merlin-eu
MERLINproject.eu
The MERLIN project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036337.

Figure 7. Strategic Actions for Engaging the Hydropower Sector in Barrier Removal. This infographic outlines five strategic actions proposed by MERLIN to involve the Hydropower Sector in barrier removal as a Nature-based Solution (NbS) for river connectivity restoration. The strategy promotes a landscape-scale approach grounded in mutual benefits, highlighting: **A.** Improved understanding of NbS within the sector; **B.** Synergies between renewable energy and restoration policies; **C.** Finance pathways aligned with sector needs; **D.** Collaborative leadership for programme delivery; **E.** Sector-specific tools for identifying suitable barriers for removal. The strategy emphasises that NbS implementation must consider operational realities and foster trust amongst public and private actors to avoid greenwashing and achieve meaningful, systemic change (Carmen and Blackstock 2025).

The resulting strategies identified common actions: gathering sector-relevant evidence, fostering awareness through dialogue, building internal capacity, shaping enabling policy and attracting investment (Bérczi-Siket et al. (2025); Fig. 7). While interest varied across sectors, shared themes emerged — particularly the need for risk management, reputational benefits and regulatory clarity. For local practitioners and project teams, the lesson is to engage sectoral actors early, adapt messaging to their priorities, and view them as co-shapers of restoration, not just external stakeholders.

Building trust and legitimacy through stakeholder engagement

Restoration is never just a technical exercise — it is inherently political. Every project touches on questions of representation, decision-making and the distribution of gains and losses. MERLIN demonstration cases confirmed this reality: despite formal participatory processes, power imbalances often persisted. Large landowners or established authorities frequently held outsized influence,

shaping decisions in ways that could marginalise other voices. Tensions rooted in cultural identity or livelihood concerns surfaced where local grievances were insufficiently acknowledged, sometimes undermining support for restoration.

Meaningful stakeholder engagement must, therefore, go beyond outreach or consultation. It involves recognising trade-offs — ecological, economic and social — not as inconvenient side effects, but as central issues that require negotiation. Justice in restoration is not just an ethical imperative; it is a practical necessity for long-term project viability.

Trust is cultivated through transparency, responsiveness and sustained presence on the ground. Projects that adapted their engagement strategies over time — whether by fostering school partnerships, building cooperative models or maintaining direct dialogue with landowners — were more successful in generating broad-based support. Notably, several demonstration teams reported that stakeholder engagement consumed a third or more of their working hours, underscoring its significance as a time-intensive, yet indispensable, part of restoration work (Ibrahim et al. 2025).

For practitioners, this means recognising stakeholder engagement as a continuous and resource-demanding process. Structured stakeholder mapping, the use of participatory standards, such as the IUCN NbS framework (Le Gouvello et al. 2023) and co-production of knowledge are valuable tools for both planning and evaluation.

Policy-makers and funders play a crucial enabling role. They can embed stakeholder engagement requirements in funding schemes, provide dedicated resources for dialogue and conflict mediation and require transparent reporting on inclusiveness, decision-making processes and the distribution of costs and benefits. When justice is embedded from the start, restoration is more likely to endure, scale and enjoy public legitimacy.

Discussion

Implementation as a social process

Implementation in the MERLIN cases unfolded as both a technical and a social process. Although often presented as ecological or engineering tasks, NbS are embedded in social and institutional contexts that shape what can be achieved. MERLIN operated within this space: restoration actions triggered interactions amongst administrations, stakeholders and governance structures that either enabled or constrained adaptive learning. Where institutional support and political commitment were strong, actors coordinated and aligned their efforts; where they were weak, implementation tended to narrow to technical delivery rather than joint learning.

Restoration success therefore depended as much on social coordination and institutional culture as on ecological design. This observation echoes broader scholarship that frames restoration as a social process of collaboration, deliberation and mutual learning (Seidl et al. 2013; Fischer et al. 2021). While overarching policy frameworks, such as the Water Framework and Habitats Directives, provided direction, progress on the ground was largely facilitated through locally orientated engagement tools — stakeholder mapping, participatory scenario development and co-designed Theory of Change pathways.

These instruments structured dialogue, revealed divergent interests and helped identify feasible entry points for cooperation, though the depth of collaboration they fostered varied across cases. In this sense, the MERLIN experience aligns with wider NbS research (Nesshöver et al. 2017; Seddon et al. 2021), showing that durable outcomes depend less on technical design than on adaptive capacity and relational trust within restoration networks (Chaffin et al. 2014).

Across the MERLIN cases, the degree of transformative momentum varied considerably. In some sites — such as the Emscher Basin restoration (Germany), Danube floodplain restoration (Austria) and Room for the Rhine (the Netherlands) — MERLIN contributed to long-standing restoration systems supported by stable governance frameworks, financing mechanisms and stakeholder partnerships. Here, its added value lay in refining ongoing transformation by adding analytical, communicative or social dimensions. Elsewhere, MERLIN's role was more pre-transformative, serving as a testing ground for new approaches in settings still lacking institutional stability or policy commitment. These ranged from pilot implementations translating theoretical ambitions into first on-the-ground actions (e.g. Hutovo Blato peatland rewetting, Bosnia; Tisza floodplain rewetting, Hungary), to incremental follow-up measures within existing initiatives (e.g. Lima River forest restoration, Portugal; Sorraia River restoration, Portugal) and even science-based proofs of concept with limited systemic reach (e.g. Beaver River engineering, Sweden). Together, these examples illustrate the diversity of governance maturity and transformative readiness across Europe's freshwater restoration landscape.

This heterogeneity aligns with transformation frameworks that distinguish between preparatory, take-off and stabilization phases (Olsson et al. 2004; Westley et al. 2011). Taken together, MERLIN's cases populate this continuum — some consolidating progress within mature governance contexts, others still exploring how collaborative learning and institutional adaptation might enable future take-off. Sustained governance support and continuity beyond project cycles will be essential to carry these experiences into systemic, long-term change.

Situating the building-block framework

The building-block framework developed in this paper serves as a synthesis device to capture the multi-faceted character of transformative action in ecosystem restoration. Similar to other approaches that decompose sustainability transformation into complementary dimensions or "leverage points" (Wiek et al. 2012; Abson et al. 2017), it aims to make complex, transdisciplinary processes more tractable and communicable. Each building block represents a functional domain of co-production, collectively spanning diagnostic (status review), normative (narratives of the future), analytical (evidence-informed approach), instrumental (resource management) and social (stakeholder engagement) dimensions.

What distinguishes this framework from most existing models is its empirical grounding in large-scale restoration practice and its reflexive treatment of science's role. Rather than prescribing transformation from a theoretical standpoint, the building blocks were inductively derived from MERLIN's cross-case synthesis, informed by the lived experience of practitioners, agencies and scientists. Science is positioned not as a central orchestrator, but as a facilitative actor, providing analytical scaffolding, methodological tools and shared

evidence bases to support social negotiation and learning. In this sense, the building-block narrative functions less as an abstract transformation theory and more as a translation framework — connecting diverse actors, knowledge forms and governance levels involved in the restoration process.

This pragmatic, practice-based orientation positions the framework at the interface between restoration ecology, governance studies and transdisciplinary sustainability science. It reflects a broader movement within sustainability and environmental research to conceptualise transformation not as a single, linear process, but as a constellation of interacting capacities — learning, experimentation, reflexivity and institutional adaptation — that co-evolve through feedback and practice (Chaffin et al. 2016; Fazey et al. 2018; Caniglia et al. 2021).

Contextual limitations and learning boundaries

MERLIN's implementation and learning processes were shaped by several structural constraints. As in many EU-funded Research and Innovation Actions, projectification — fixed timelines, deliverables and funding structures — created space for experimentation and co-production, but limited institutional continuity (Hodge and Adams 2016). These conditions enabled social and technical innovation across the demonstrations, yet often prevented their integration into long-term governance, administrative routines or stable financing pathways.

As discussed above, governance readiness varied widely across MERLIN's demonstration contexts, shaping both the scope for experimentation and the durability of outcomes (Chaffin et al. 2014; Morrison et al. 2019). In some regions, highly institutionalised systems provided stable frameworks for coordination, while in others, pilot initiatives relied on temporary coalitions and project-based funding, often under NGO leadership (Lockwood 2010; Hodge and Adams 2016). This diversity provided valuable comparative insight, but also limited the generalisability of lessons beyond context. In several instances, progress depended less on formal authority than on individual leadership and relational trust — a factor known to shape adaptive governance across both weakly- and strongly-institutionalised systems (Wyborn 2015).

Another boundary concerned the role of science, which varied markedly across the demonstration cases. While MERLIN was designed with a transdisciplinary ethos, the actual degree of scientific influence depended less on formal project design than on the pre-existing relationships and trust between researchers and the practitioners executing restoration on the ground. In several long-standing collaborations, scientists acted as embedded partners, contributing to joint sense-making and adaptive planning. In others, where such relational capital had to be built from scratch, their role remained largely supportive, providing evidence, analytical clarity and methodological tools to provide information for implementation. This diversity underscores a broader insight from transdisciplinary research: that the position of science within transformative processes is co-defined by history, trust and institutional context, assets that cannot be manufactured within a single project cycle (Beck et al. 2014; Wyborn et al. 2018).

Taken together, these limitations define the learning boundaries within which MERLIN operated: constrained time horizons, uneven governance — rooted in context-specific institutional and power configurations (Chaffin et al. 2014; Bodin 2017; Morrison et al. 2019) — and a differentiated, but largely facilitative

role of science. Acknowledging these boundaries is crucial for recognising which forms of transformation are realistic within project-based innovation and for identifying the enabling conditions needed to move beyond them.

Conclusions

This paper synthesises insights from 18 MERLIN freshwater restoration cases and organises them into five building blocks — status review, future narratives, evidence use, resource management and stakeholder engagement — that, together, outline the enabling conditions for effective and scalable restoration. Rather than proposing new tools, it integrates recurring lessons into a practical framework for actors operating at the science–policy–practice interface.

The analysis shows that scaling up Nature-based Solutions depends less on standardised models than on navigating interdependent challenges in diverse contexts. Success requires integrating the five building blocks, maintaining meaningful stakeholder engagement and applying adaptive approaches to planning and implementation. These findings complement existing scholarship, while grounding it in a coordinated portfolio of European demonstration cases.

By clarifying the structural conditions that support durable restoration, the framework can guide future initiatives under the European Green Deal and the Nature Restoration Regulation. Its value lies in usability: offering restoration teams, policy-makers and funders a coherent, context-sensitive orientation for translating broad policy goals into effective local action.

Acknowledgements

We thank Jörg Strackbein (University of Duisburg–Essen) and Petra Schneemann (Werbeagentur Schnee auf Moos, Vienna) for their excellent work in designing the figures. We further extend our gratitude to the entire MERLIN consortium, with special appreciation for the case study practitioners, whose practical insights and sustained engagement were instrumental in bringing the MERLIN project to life.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

AI-assisted language tools were used only for minor editorial support. All scientific content, interpretations, and conclusions are the sole responsibility of the authors.

Funding

The MERLIN project (https://project-merlin.eu) has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036337.

Author contributions

SB conceived and designed the research; SB, GA, ABP, ABS, KB, TB, LC, NG, EHH, TO, EP, JR, ASK, DH acquired funding; SB, DH administered the project; SB supervised the work; SB, ABS, KB, EC, XG, EHH, AI, SK, MIL, LP, JR, AS, KW conducted the investigation; SB, AB, KB, EC, XG, EHH, AI, SK, MIL, LP, JR, AS, KW wrote the original draft; all authors reviewed and edited the manuscript.

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Data availability

All of the data that support the findings of this study are available in the main text.

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